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Choice of Computer-Generated Random Numbers Whose Statistics Match Those of Experimentally Measured Ambient Noise

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ABSTRACT

The family of fluctuation-sensitive processors known as the WISPR family, has been demonstrated to significantly improve the detection of submerged sources in a variety of experimental cases. However, since the experiments do not cover all possible ranges of signal and environmental parameters, it is necessary to perform simulations in order to develop a more complete understanding of processor performance under different conditions. The choice of computer-generated random numbers (RNs) whose statistics match those of experimentally measured ambient noise for such simulations is discussed in the present report. Both the statistics of voltage time series and the statistics of power decibel levels of specific frequency bins calculated by fast Fourier transform have been used for comparison between the computer-generated RNs and experimentally measured ambient noise. Experimental ambient noise data from the Black Sea and the Pacific Ocean have been used. The results show that the statistics of computer-generated uniform RNs and Gaussian RNs match those of experimental ambient noise data very well. Therefore, these RNs should provide realistic simulation of ambient noise in simulations of WISPR processor performance.

1. INTRODUCTION

The investigations reported below have been motivated by the need for realistic computer-generated random numbers (RNs) for use in simulations of a family of fluctuation-sensitive processors known as the WISPR family of processors [1-4]. The WISPR family of processors has been demonstrated to significantly improve the detection of submerged sources in a variety of experimental cases [1-4]. However, since the experiments do not cover all possible ranges of signal and environmental parameters, it is necessary to perform simulations in order to develop a more complete understanding of processor performance under different conditions. Since processor performance is sensitive to ambient noise, it is important to choose computer-generated RNs whose pertinent statistical features closely resemble those of experimentally measured ambient noise.

In the discussion below, both the statistics of voltage time series and the statistics of power decibel levels of specific frequency bins calculated by fast Fourier transform (FFT) are used for comparison between computer-generated RNs and experimentally measured ambient noise. Experimental ambient noise data from the Black Sea and the Pacific Ocean have been used.

2. EXPERIMENTAL DATA

Comparisons of computer-generated RNs have been made with measured data from the Black Sea, and from the Pacific Ocean [5]. The ambient noise measurements in the southwestern Black Sea were taken in the Summer using a 64 element horizontal line array (hydrophone spacing: 2 m), towed at average array depths ranging from 55 to 77 m. Water depth was approximately 1000 m. Shipping traffic ranged from moderate to heavy. The sea state was approximately 3. The sound speed profile at the site during the measurements is shown in Fig. 1. The voltage time series from the array of hydrophones have been digitized at a sampling rate of 1500 Hz.

The Pacific Ocean measurements were also taken in the Summer, and the measurement site is shown in Fig. 2. A 30 element vertical line array (hydrophone spacing: 3.05 m) was moored to the bottom, and a 16 element horizontal line array (hydrophone spacing: 1.8 m) was laid on the sea floor in waters of depth 137 m [5]. Commercial shipping was moderate to heavy, and the sea state was approximately 3. The sound speed profile for this site during the measurements is given in Fig. 3. The voltage time series from the array of hydrophones have been digitized at a sampling rate of 2000 Hz.

3. STATISTICS OF VOLTAGE TIME SERIES

The computer-generated RNs were generated using MATLAB on a SUN workstation [6]. Uniform RNs were generated by the command "rand", and Gaussian RNs by the command "randn". The probability density function (PDF) of a sequence of 20,000 such numbers in each case is shown in Figs. 4(a) and (b), respectively. The scale on the X-axis has been normalized in terms of the standard deviation of the numbers.

The mean, skew, standard deviation (labeled "sigma"), and kurtosis of successive non-overlapping blocks of 1024 uniform RNs are shown in Fig. 5(a). The mean and the standard deviation values have been normalized in terms of the mean of the standard deviations of all the 100 blocks. Similar graphs for Gaussian RNs are shown in Fig. 5(b). Here, the kurtosis values fluctuate around 3, which is the theoretically expected value for a perfectly Gaussian distribution.

Similar graphs for digitized voltage time series data from the Black Sea, sampled at the rate of 1500 Hz, are shown in Fig. 5(c). While Fig. 5(c) is for hydrophone 10, results for other hydrophones are very similar.

Based on comparison of Figs. 5(a)-(c), the statistics of the computer-generated Gaussian RNs resemble closely those of the experimental data from the Black Sea. In both cases (Figs. 5(b) and (c)), the skew values fluctuate around zero, and the kurtosis values fluctuate around 3. The kurtosis values of the computer-generated uniform RNs fluctuate around 1.8.

4. STATISTICS OF POWER DECIBEL LEVELS OF SPECIFIC FREQUENCY BINS CALCULATED BY FFT

The difference between uniform RNs and Gaussian RNs evident from the statistics in Figs. 5(a) and (b) disappears when the statistics of power decibel levels of specific frequency bins are considered. This is illustrated in Figs. 6(a) and (b), where the PDFs of uniform RNs and Gaussian RNs, respectively, are plotted. In each case, 128 point FFTs (weighted with Hann windows) of successive non-overlapping sections of the RNs have been calculated. Sample sizes of 5000 power decibel levels were used to calculate the PDFs. The distributions in Figs. 6(a) and (b) are very nearly the same. This implies that values of standard deviation, skew, kurtosis, and the higher moments must be very nearly the same for both distributions. The PDFs in Figs. 6(a) and (b), due to uniform RNs and Gaussian RNs respectively, are very similar (though not identical) to the experimental PDFs from a Pacific Ocean ambient noise measurement [5] shown in Fig. 6(c). Here, decibel levels of power in frequency bin 6 (171.9-203.1 Hz band) obtained from 64 point FFTs (weighted with Hann windows) of successive non-overlapping sections of digitized voltage time series data has been analyzed. Power levels from 3492 FFTs were used to calculate each distribution. PDFs of 10 hydrophones between the depths of 43.6 m and 137.0 m (sea floor) are superposed.

Figure 7(a) shows the standard deviation, skew, and kurtosis of 100 power decibel levels in each frequency bin, resulting from 128 point FFTs of successive non-overlapping sections of uniform RNs, generated by MATLAB. Figure 7(b) shows similar graphs for Gaussian RNs generated by MATLAB. Figure 7(c) shows similar graphs for digitized voltage time series data from the Black Sea. Data are from hydrophone 10, with a sampling rate of 1500 Hz. Results for other hydrophones are very similar.

The results in Figs. 7(a)-(c) are summarized in Figs. 7(d) and (e) for easy comparisons. Here, the mean value of each quantity, viz. standard deviation, skew, or kurtosis, calculated over all 64 frequency bins, has been represented as a horizontal straight line. Since the average values of standard deviation and kurtosis are too close, two figures are used to avoid confusion. The dotted lines representing experimental values are for hydrophones 10, 15, and 20. One of the dotted lines (experimental) and the dashed line (uniform RN) are not noticeable among the set of skew graphs, because they coincide with the solid line (Gaussian RN). Figures 7(d) and (e), as well as the qualitative similarity of Figs. 7(a)-(c), clearly demonstrate that the statistics of the power decibel levels of both the uniform RNs and the Gaussian RNs are very nearly equal to those of experimentally measured ambient noise.

5. CONCLUSIONS

Since the WISPR family of processors use the power levels from FFTs as inputs, the striking similarity of the statistics of the uniform RNs and the Gaussian RNs with those of experimentally measured ambient noise demonstrated in Figs. 6(a)-(c), and Figs. 7(a)-(e), suggest that either of these RNs can be used as artificial noise for simulations of WISPR processor performance. This conclusion is especially true for the two processors known as WISPR and AWSUM, which depend only on power values [1-4]. The processor known as WISPR-PHASE includes phase variations of digitized voltage time series data, in addition to power values [1-4]. It is possible that the lower kurtosis value (1.8) of the uniform RN sequence shown in Fig 5(a), compared to the higher kurtosis value (3.0) of the experimental data shown in Fig. 5(c), may indicate a somewhat different prediction of WISPR-PHASE performance if uniform RNs are used for that simulation. But the agreement of the statistics of Gaussian RNs in Fig. 5(b) with the experimental statistics in Fig 5(c) suggests that Gaussian RNs would be appropriate for the simulation of the WISPR-PHASE processor.

The similarity of the power decibel level statistics of the uniform RNs and the Gaussian RNs with the corresponding statistics of the Pacific Ocean data (illustrated by Figs. 6(a)-(c)) as well as the Black Sea data (illustrated by Figs. 7(a)-(e)), further strengthens the reliability of both these RNs for WISPR processor simulations.

ACKNOWLEDGMENTS

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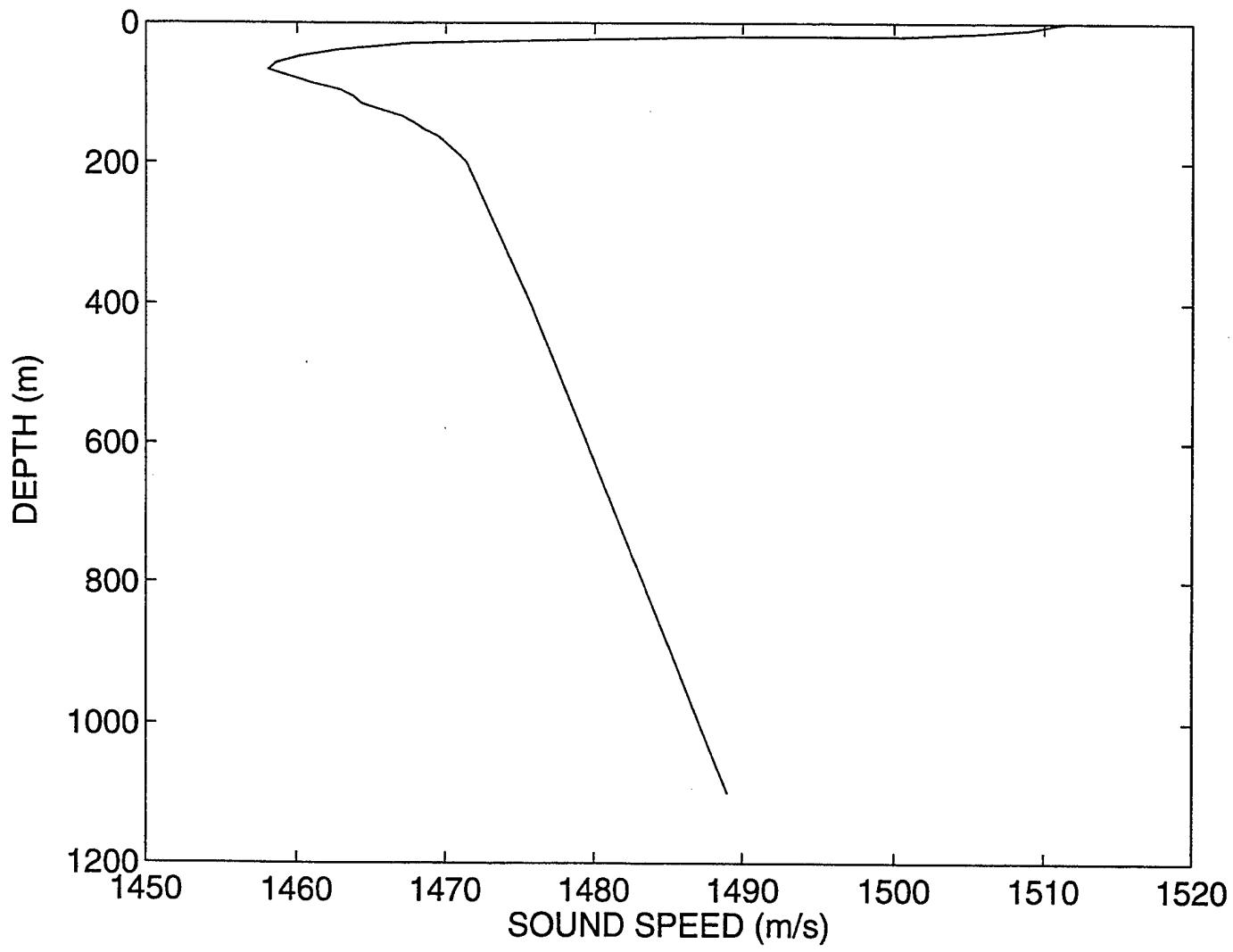
Figure 1. Sound speed profile for the southwestern Black Sea site during the measurements.
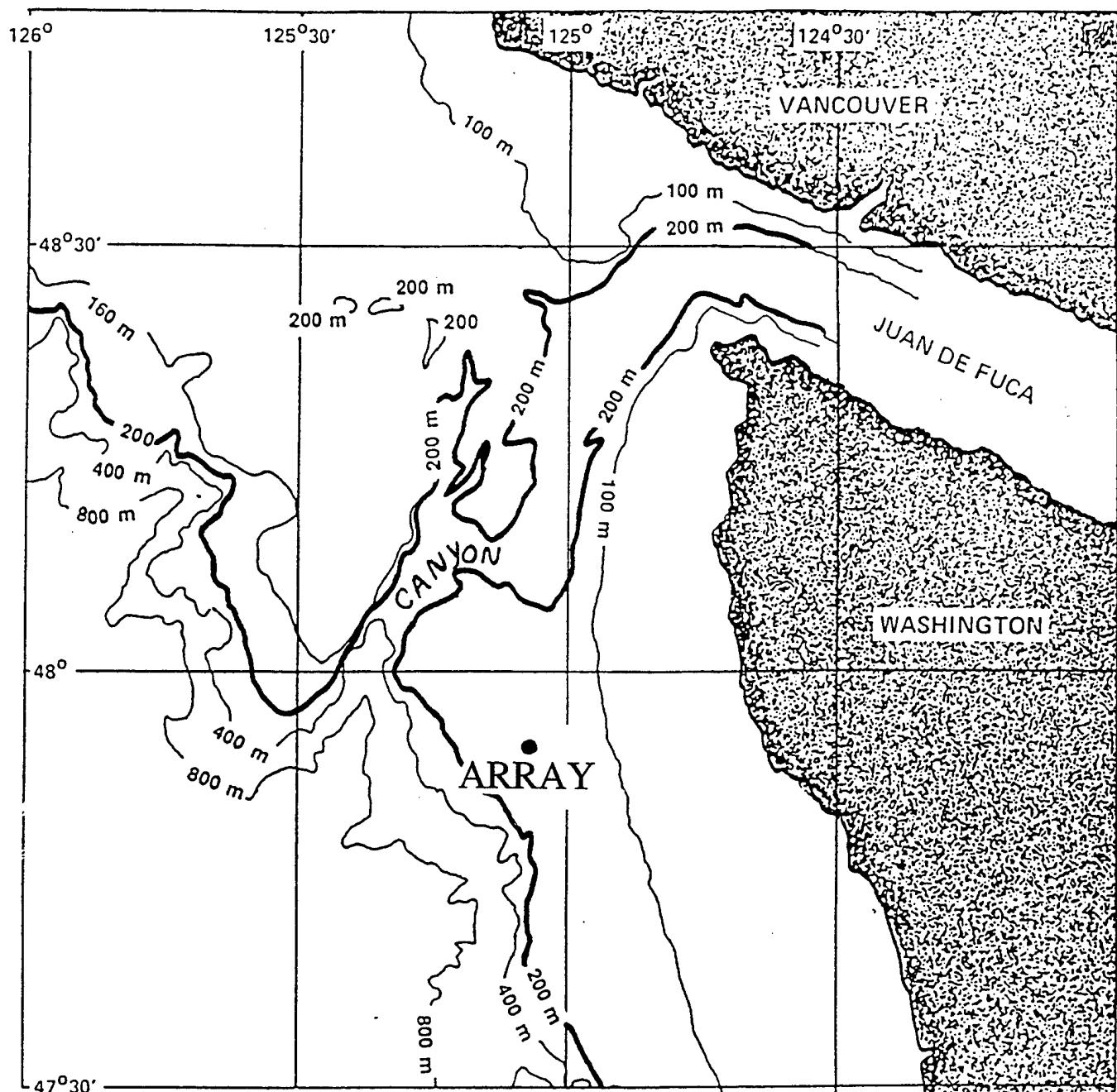
Figure 2. Location and bathymetry of the Pacific Ocean ambient noise measurement site
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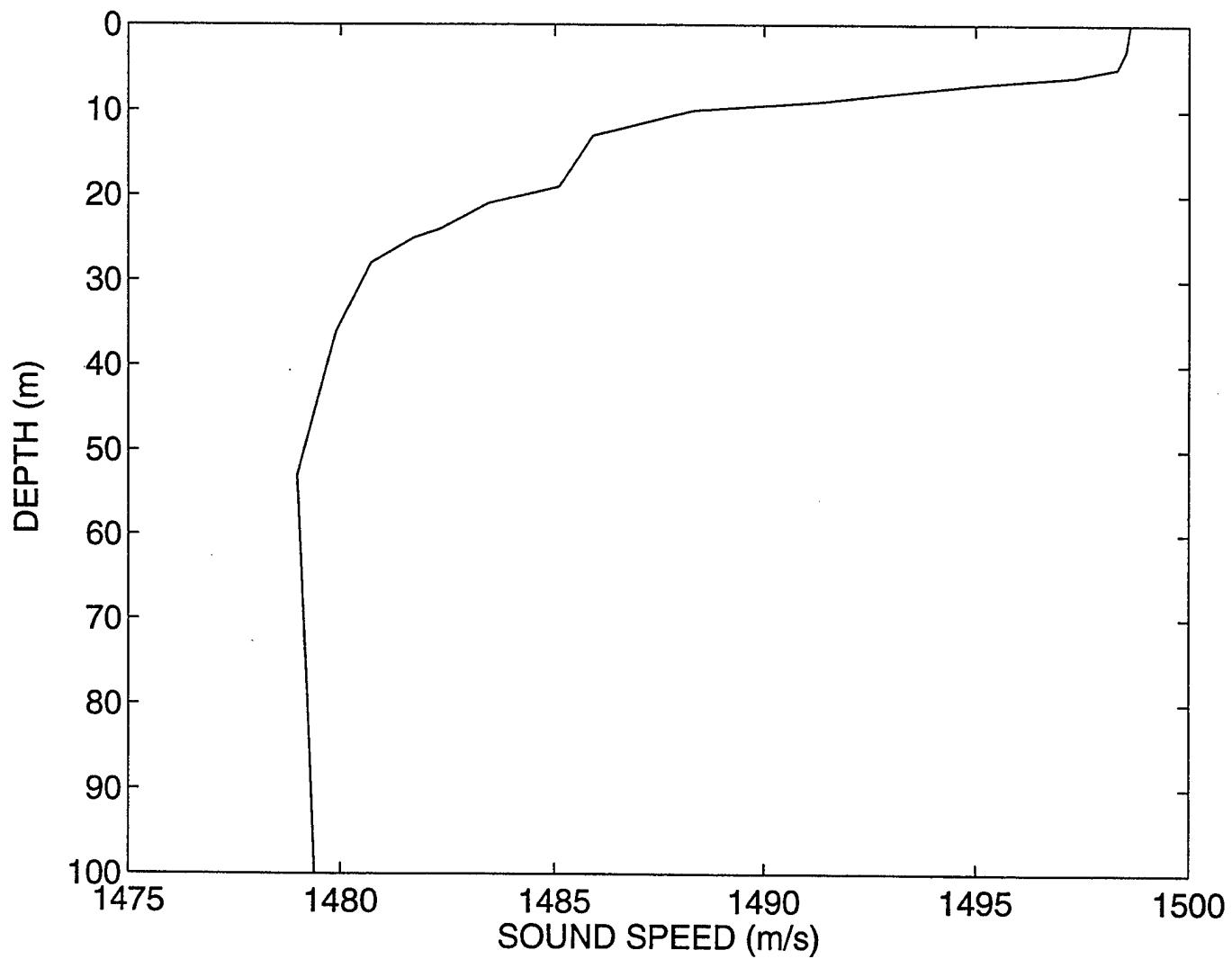
Figure 3. Sound speed profile for the Pacific Ocean site during the measurements.
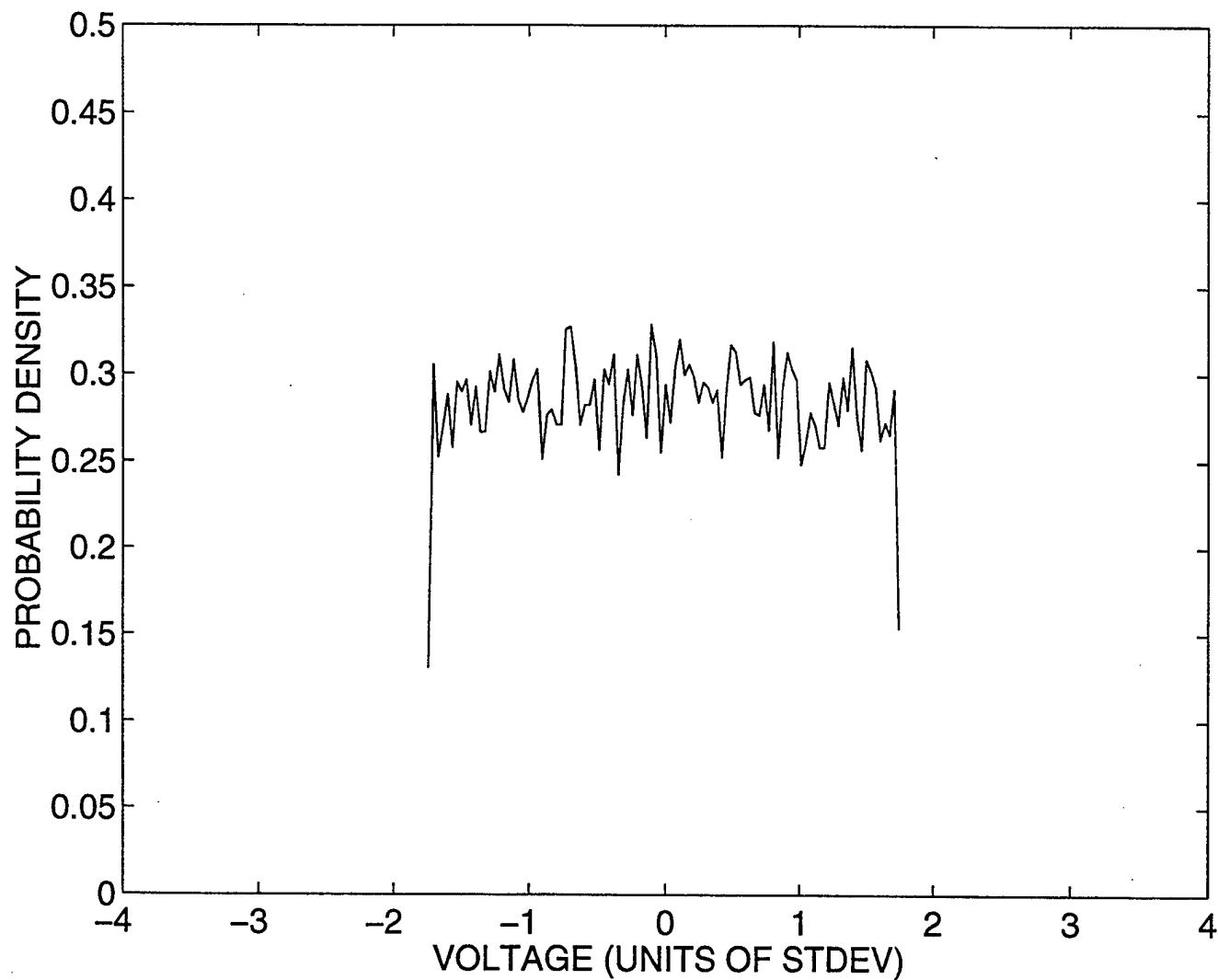
Figure 4(a). PDF of a sequence of 20,000 uniform RNs generated by MATLAB.
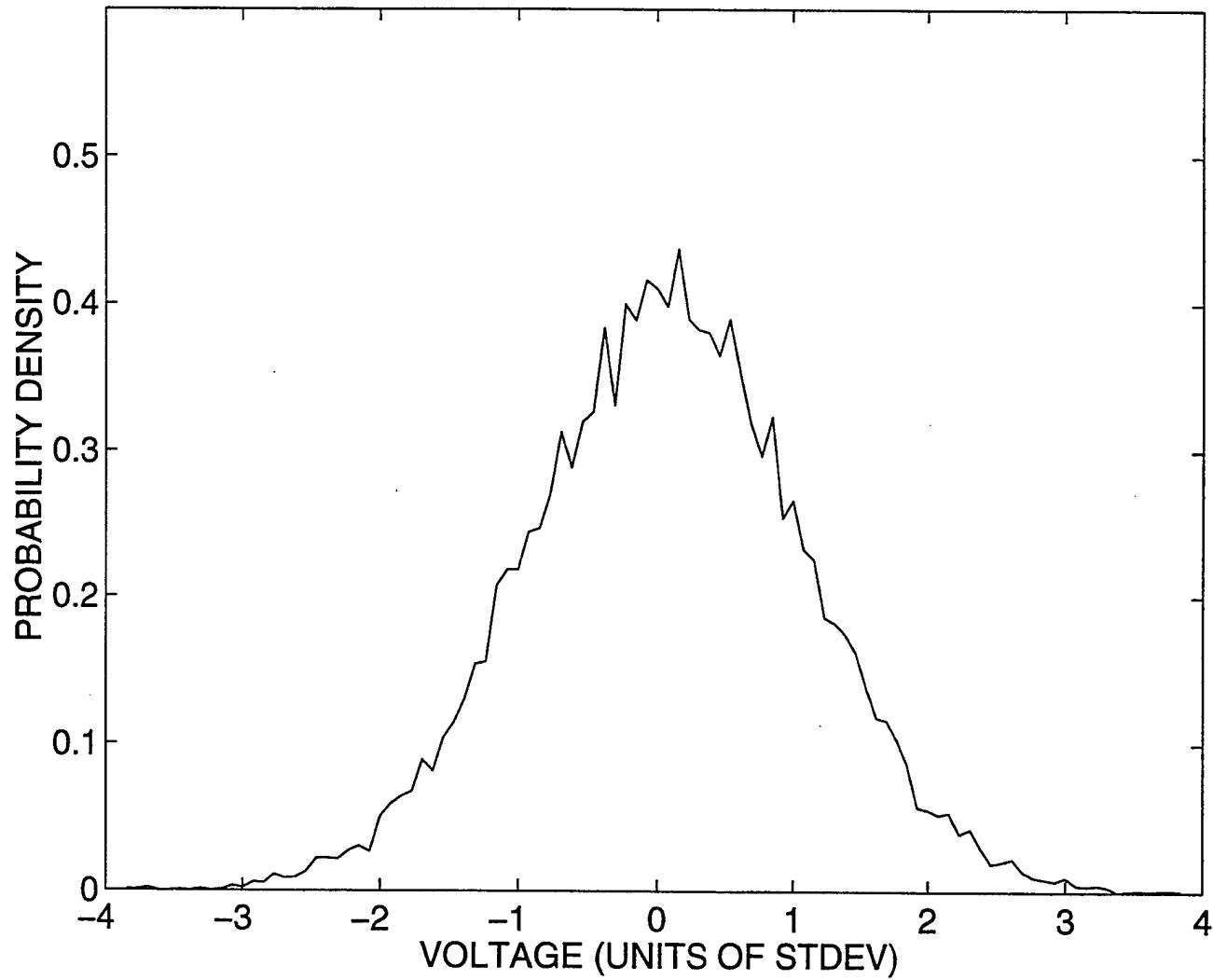
Figure 4(b). PDF of a sequence of 20,000 Gaussian RNs generated by MATLAB.
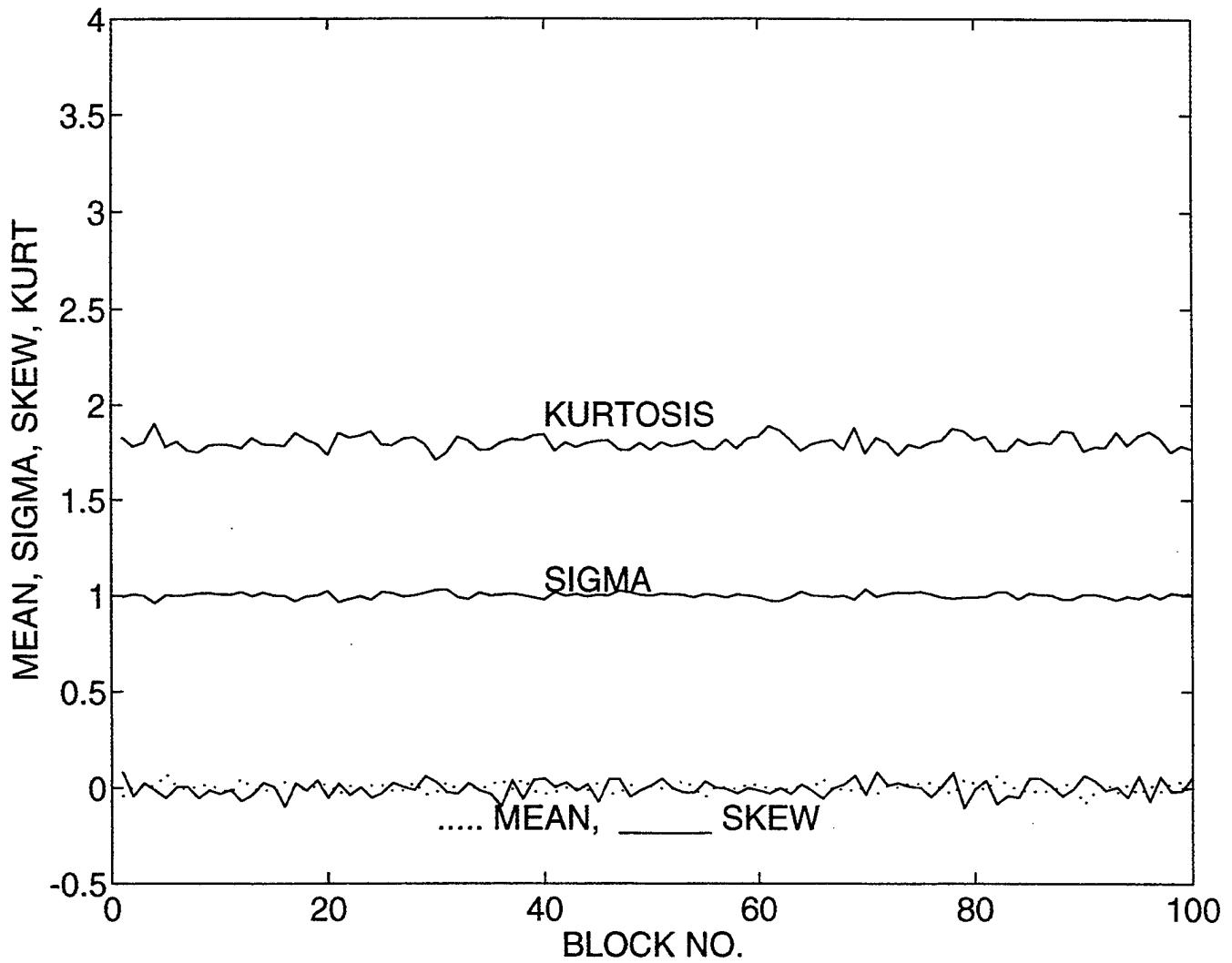
Figure 5(a). The mean, skew, standard deviation (labeled "SIGMA"), and kurtosis of successive non-overlapping blocks of 1024 computer-generated uniform RNs.
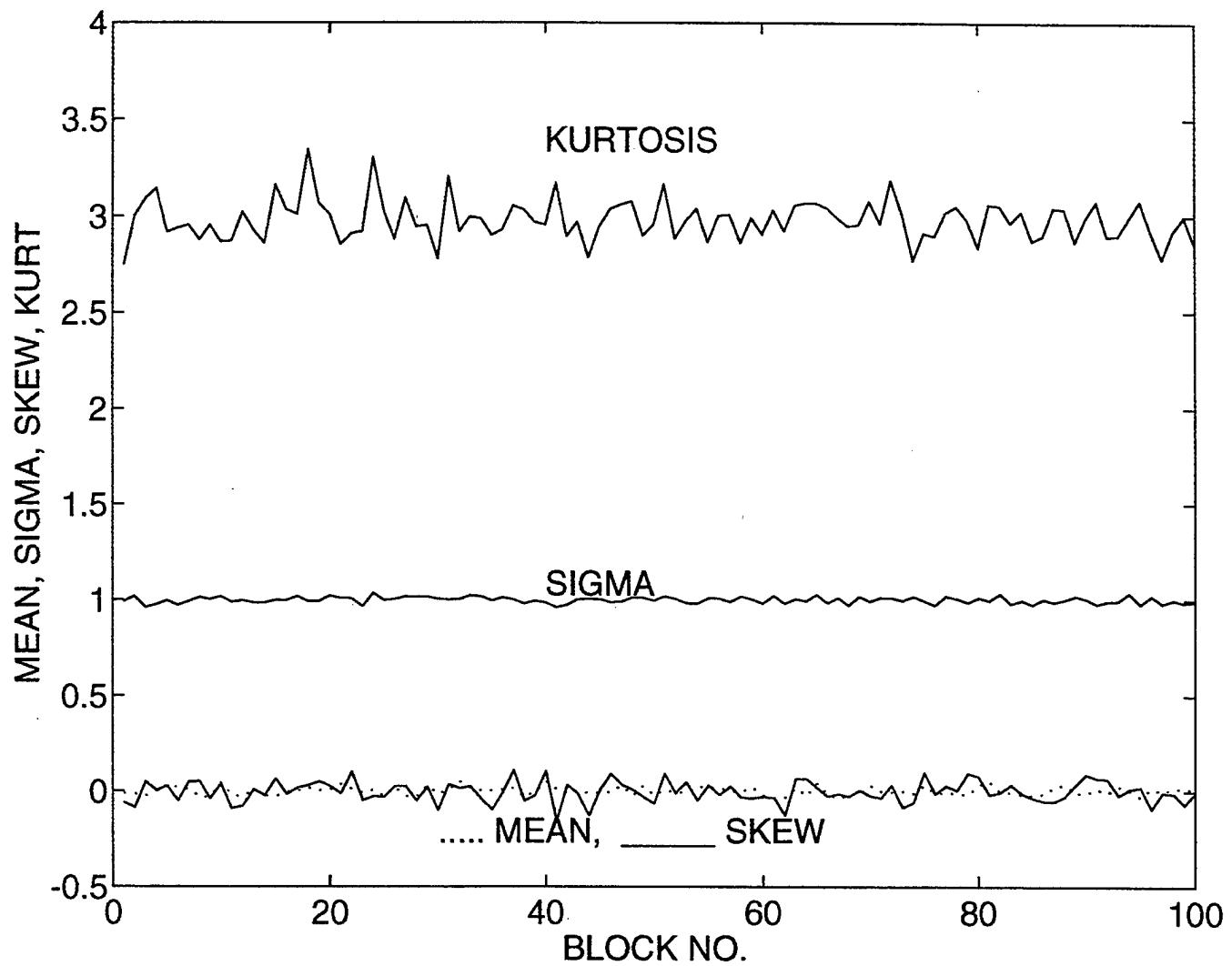
Figure 5(b). The mean, skew, standard deviation (labeled "SIGMA"), and kurtosis of successive non-overlapping blocks of 2048 computer-generated Gaussian RNs.
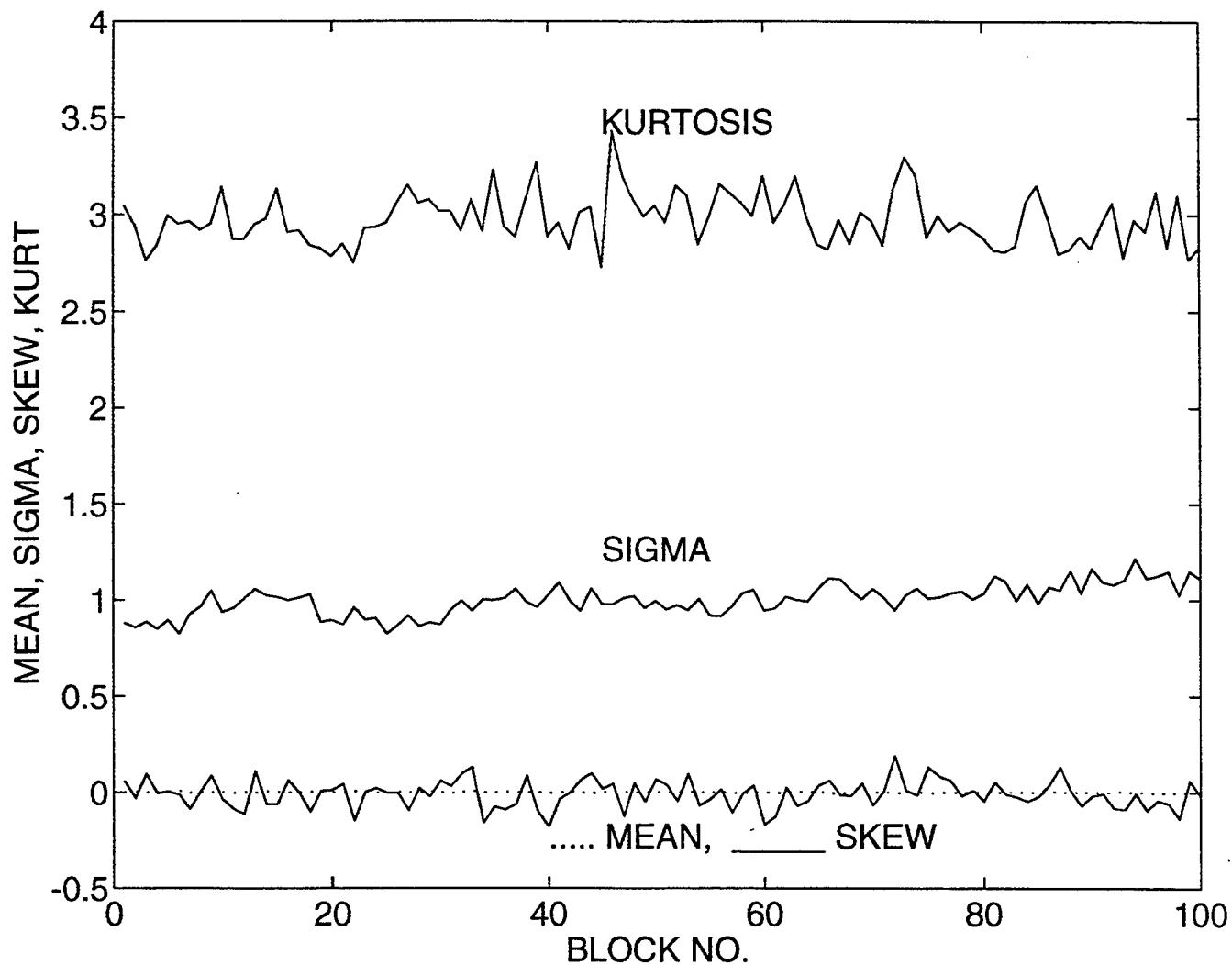
Figure 5(c). The mean, skew, standard deviation (labeled "SIGMA"), and kurtosis of successive non-overlapping blocks of 2048 digitized voltage time series data from the Black Sea. Data are from hydrophone 10. The sampling rate was 1500 Hz.
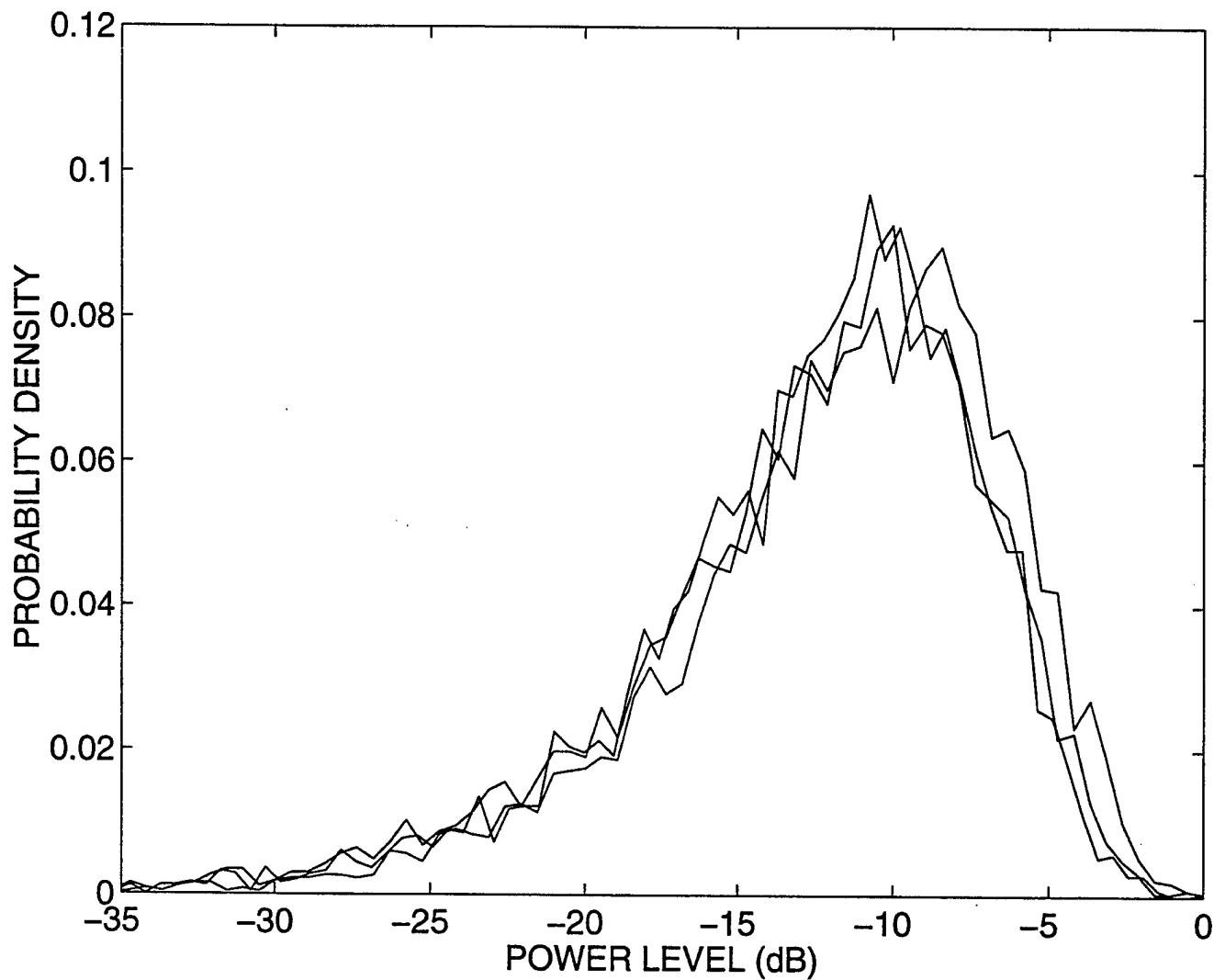
Figure 6(a). PDF of decibel levels of power in frequency bin 30 obtained from 128 point FFTs of successive non-overlapping sections of uniform RNs generated by MATLAB. Power levels from 5000 FFTs were included. PDFs for frequency bins 31 and 32 are superposed.
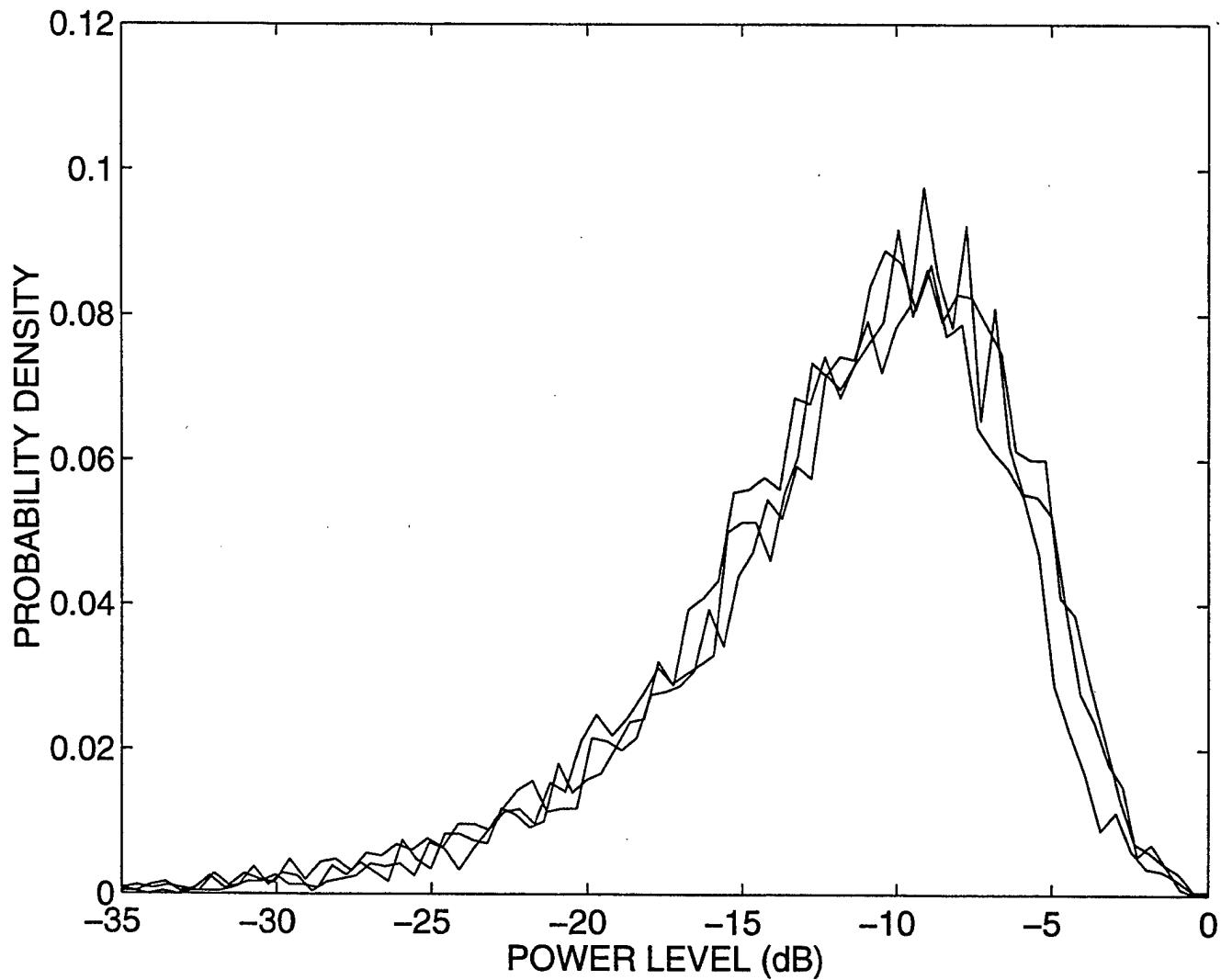
Figure 6(b). PDF of decibel levels of power in frequency bin 30 obtained from 128 point FFTs of successive non-overlapping sections of Gaussian RNs generated by MATLAB. Power levels from 5000 FFTs were included. PDFs for frequency bins 31 and 32 are superposed.
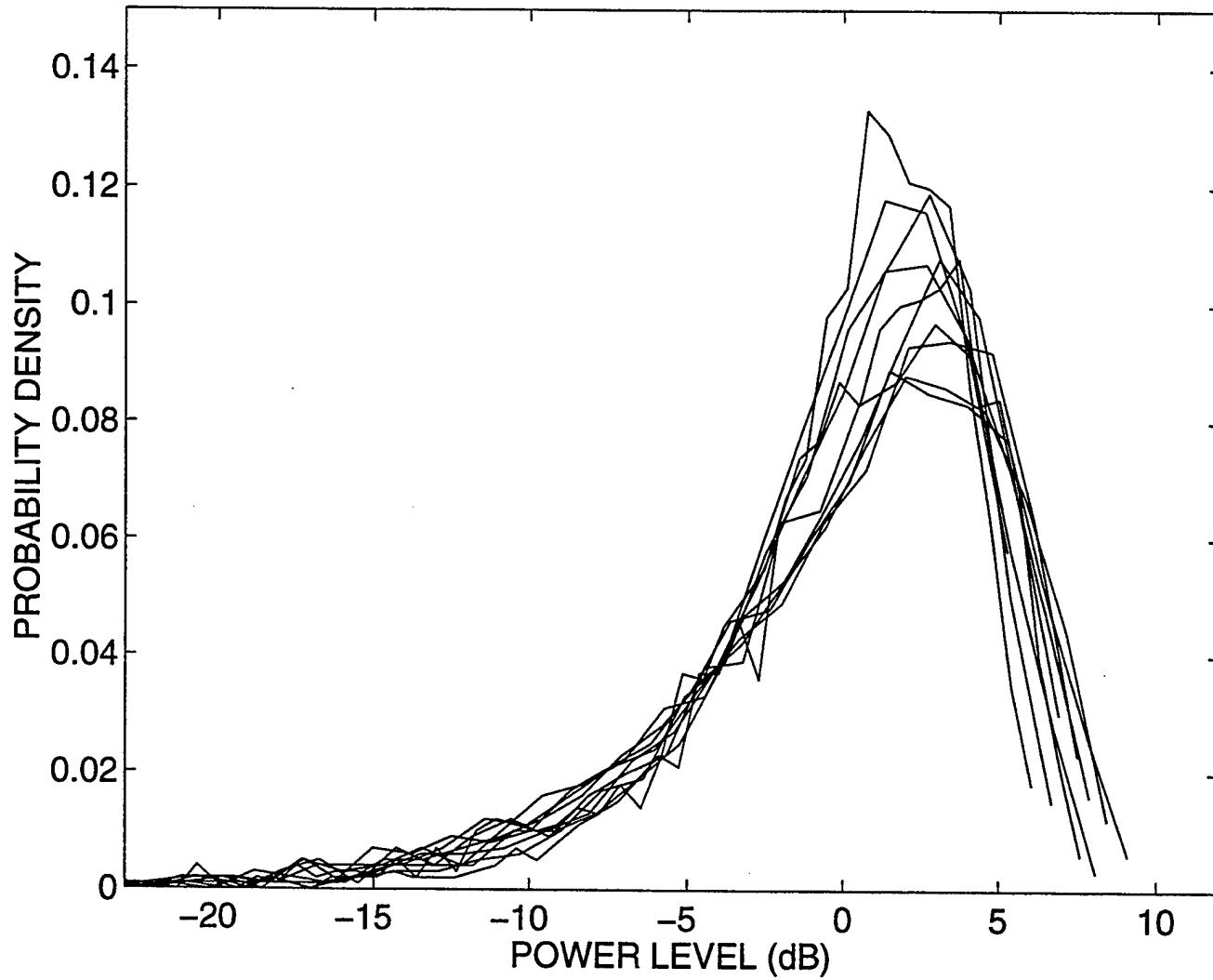
Figure 6(c). PDF of decibel levels of power in frequency bin 6 (171.9-203.1 Hz band) obtained from 64 point FFTs of successive non-overlapping sections of digitized voltage time series data from a Pacific Ocean measurement. Power levels from 3492 FFTs were included. PDFs of 10 hydrophones between the depths of 43.6 m and 137.0 m (sea floor) are superposed [5].
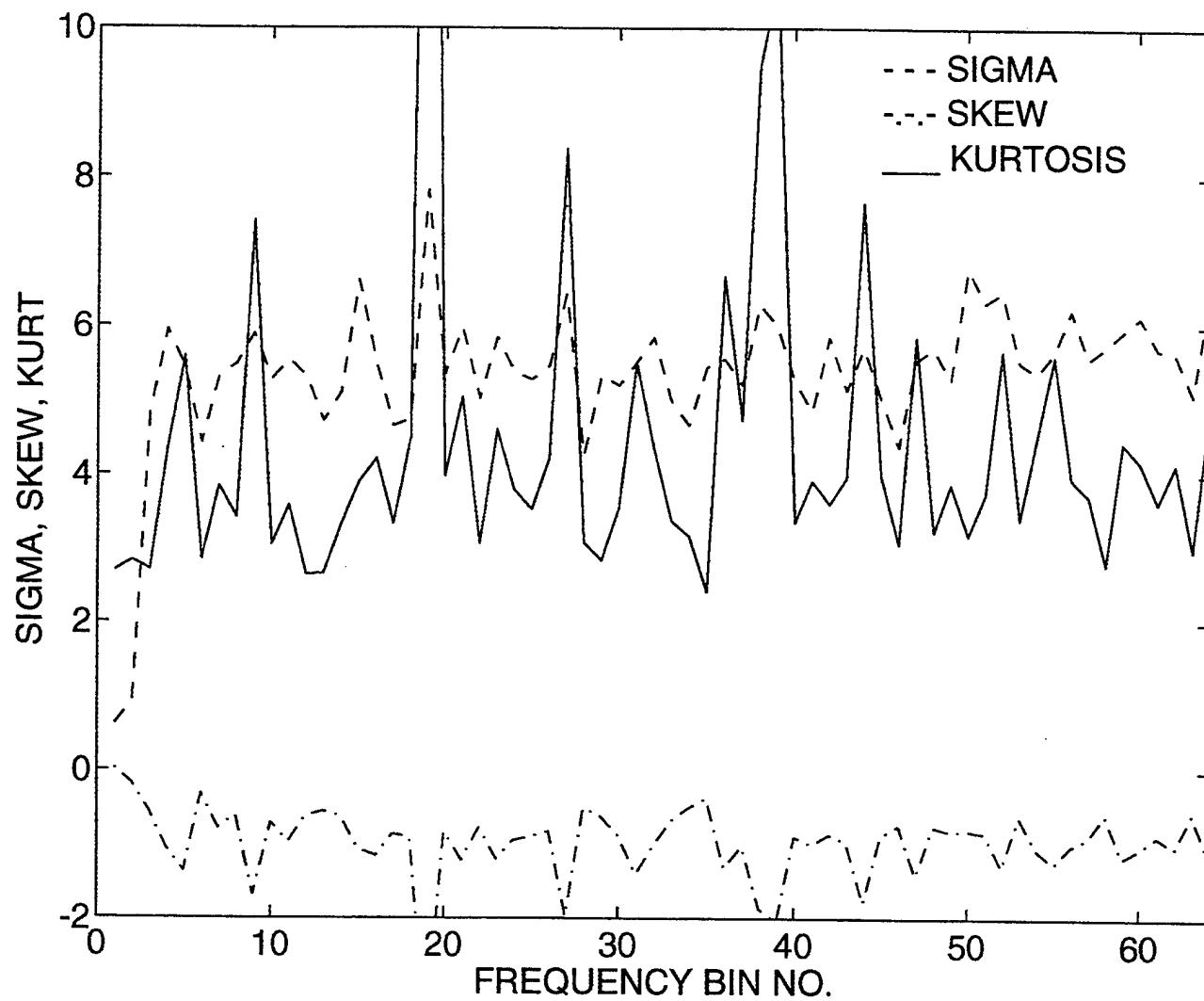
Figure 7(a). For each given frequency bin, the standard deviation (labeled "SIGMA"), skew, and kurtosis of 100 power decibel levels resulting from 128 point FFTs of successive non-overlapping sections of uniform RNs, generated by MATLAB.
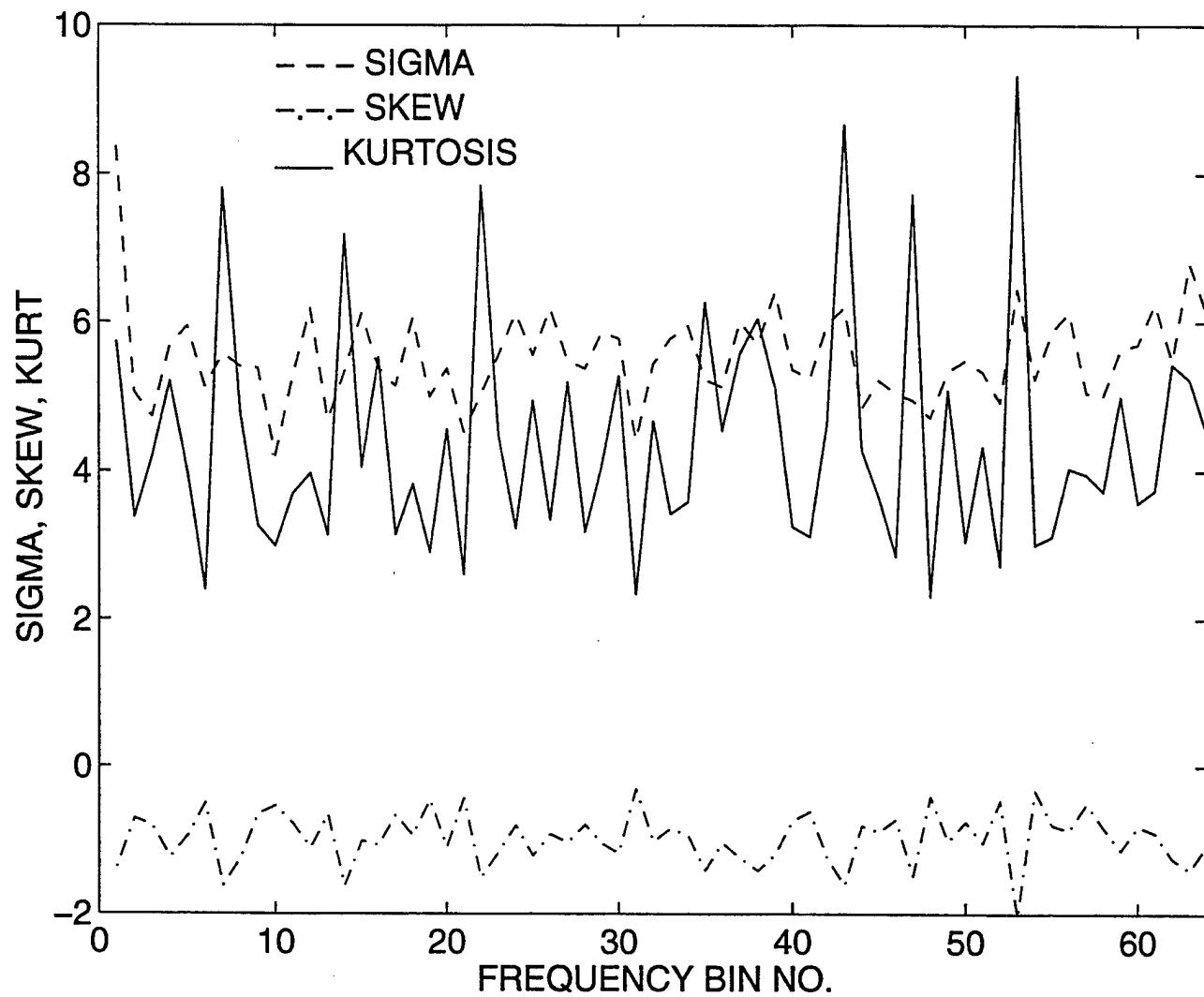
Figure 7(b). For each given frequency bin, the standard deviation (labeled "SIGMA"), skew, and kurtosis of 100 power decibel levels resulting from 128 point FFTs of successive non-overlapping sections of Gaussian RNs, generated by MATLAB.
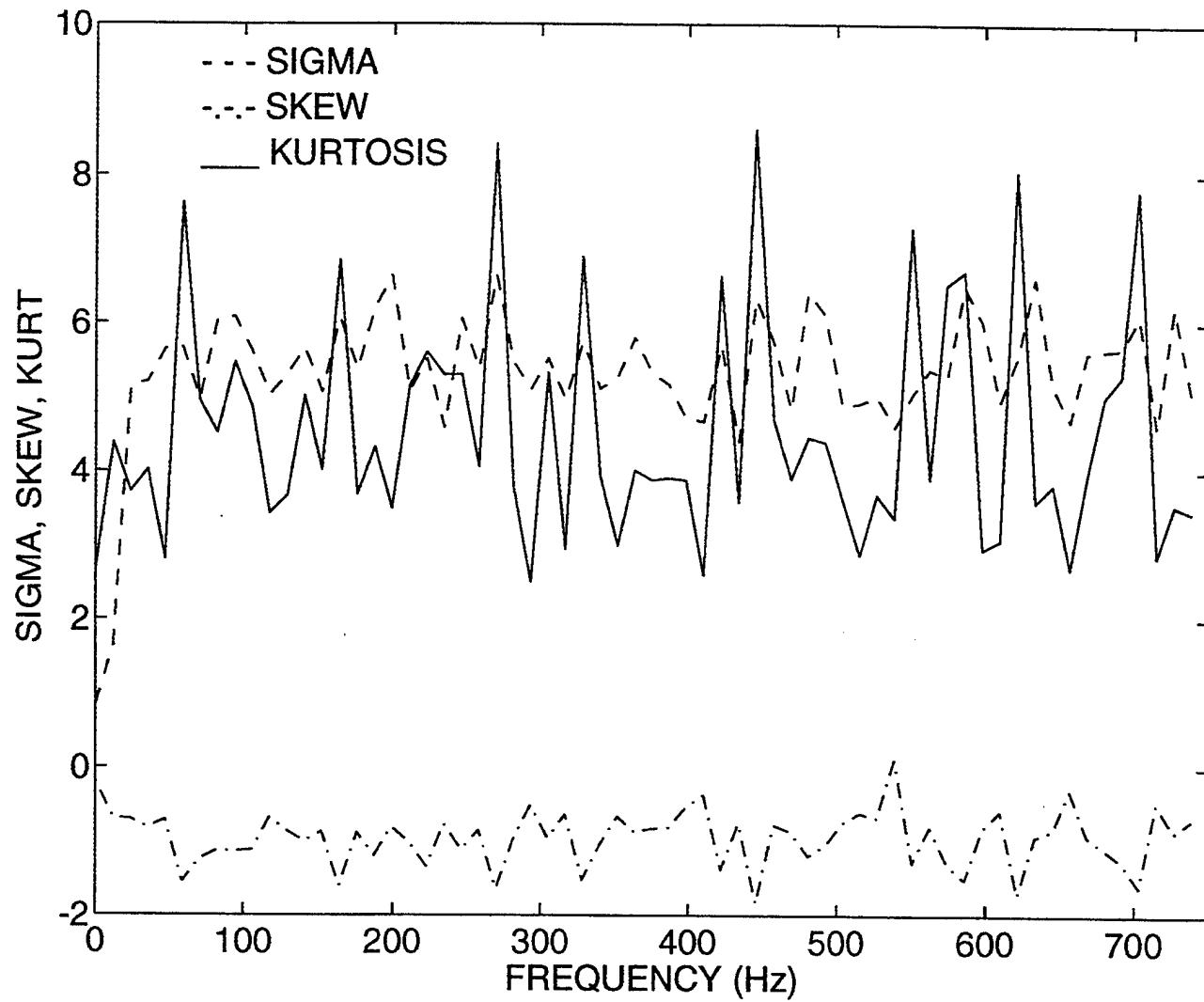
Figure 7(c). For each given frequency bin, the standard deviation (labeled "SIGMA"), skew, and kurtosis of 100 power decibel levels resulting from 128 point FFTs of successive non-overlapping sections of digitized voltage time series data from the Black Sea. Data are from hydrophone 10. The sampling rate was 1500 Hz.
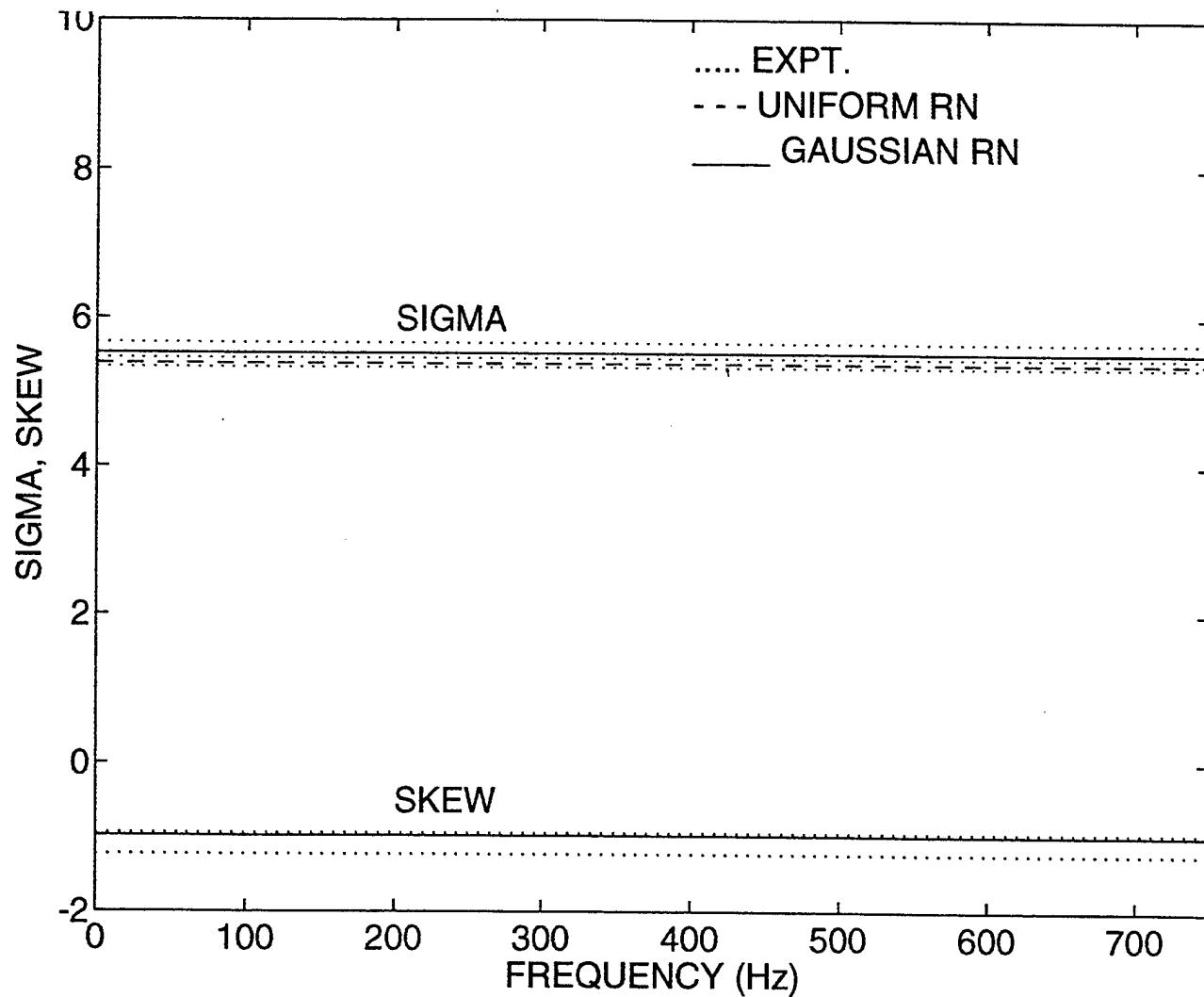
Figure 7(d). The mean value of standard deviation (labeled "SIGMA") and the mean value of skew, calculated over all 64 frequency bins from Figs. 7(a), (b), or (c), represented as a horizontal straight line. The dotted lines represent data from hydrophones 10, 15, and 20.
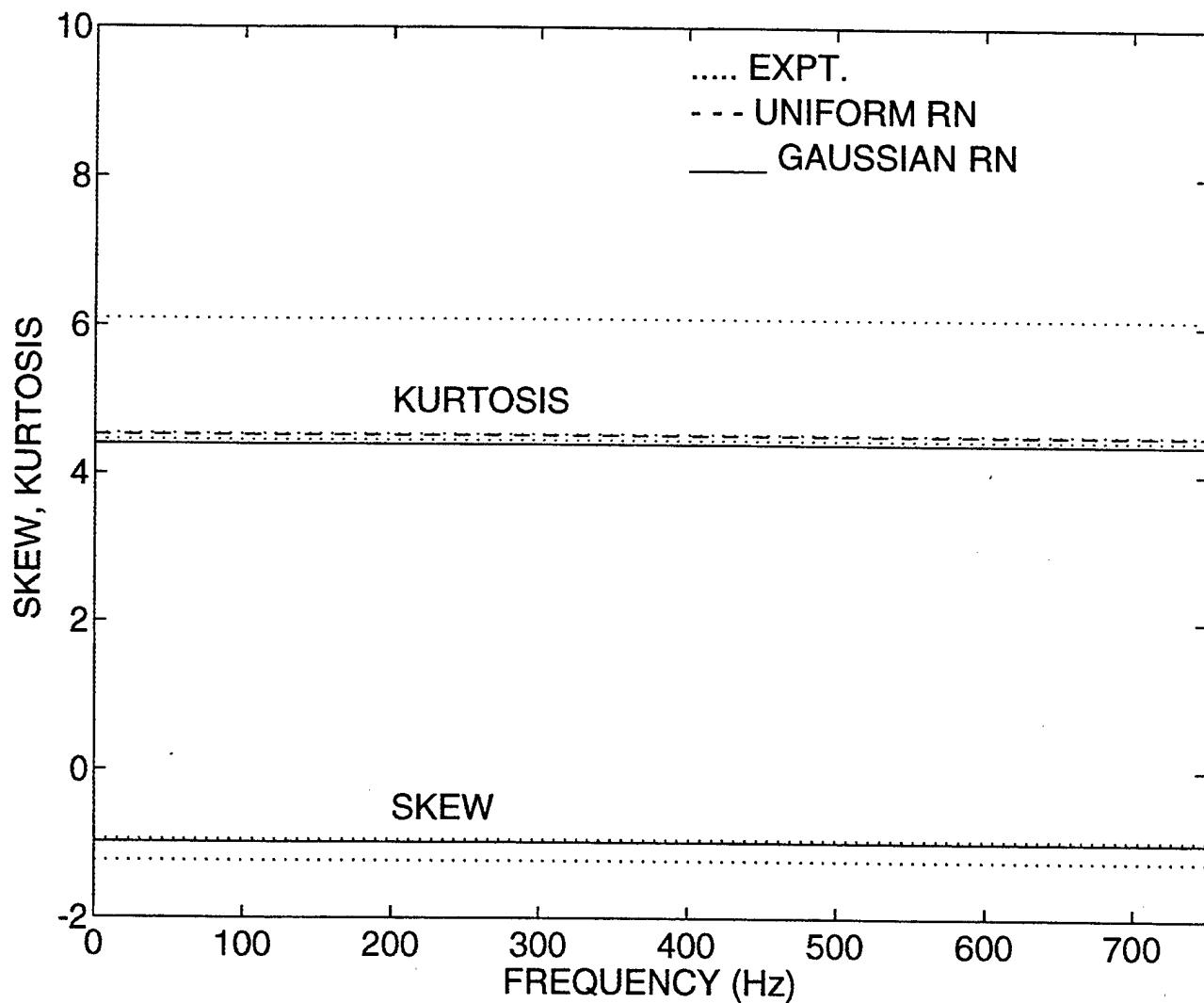
Figure 7(e). The mean value of skew, and the mean value of kurtosis, calculated over all 64 frequency bins from Figs. 7(a), (b), or (c), represented as a horizontal straight line. The dotted lines represent data from hydrophones 10, 15, and 20.